of which is to be thrown into the formalin jar, one of these tags is attached to a leg and its number recorded with the original entry in the record book. From this record the locality from which the specimen came and its species can be determined. Many times it pays to seek further information concerning a particular specimen by field contact with the man who killed it. Mr. Joseph Buff, raw-fur dealer in Syracuse, who collected for me a generous number of weasel and mink carcasses, used a small shipping tag on which information was written with a soft pencil and then tied to the carcass before placing it in formalin. This method requires a little more time but is of greatest help to the investigator.

R. A. JOHNSON

SPECIAL ARTICLES

THE FUNCTION OF THE AIR SACS IN HOLOPNEUSTIC INSECTS

AIR sacs are present in probably all of the flying and in many of the non-flying insects. In the past, two different functions have been ascribed to these structures in holopneustic forms, but the evidence offered has been far from convincing. Newport[1] observed that the number and volume of the air sacs were correlated with the powers of flight of the insect, and was led to the belief that they serve for buoyancy during flight by lessening the specific gravity of the body. Such a function is manifestly impossible, but is still held at the present time. A late text-book of entomology[2] states (p. 119):

> As the air sacs lessen the specific gravity of the insect they probably aid in flight, as filling the lungs with air makes it easier for a man to float in water; in each case there is a greater volume for the same weight.

Another and more logical view is that the air sacs are merely reservoirs or stores for air, especially well developed in those forms which consume a great deal of oxygen in flight or active movement. There are several reasons for considering such a simple explanation inadequate. There would seem to be no advantage to an insect in having air reservoirs within the body when the whole atmosphere is a reservoir just a few millimeters away through the open spiracles. The air in the sacs, unless constantly renewed, could not serve as a store for very long, since less than 20 per cent. of it is oxygen, and the total volume of the sacs is small as compared with the volume of oxygen the animal uses in an hour. There would also seem to be little advantage in having a great number of small sacs rather than a few large ones.

The explanation suggested here avoids these difficulties and accounts for the parallel development with the powers of flight and activity. This explanation is that the function of the air sacs is chiefly mechanical in allowing a considerable volume of air to be inhaled and exhaled, thereby causing a ventilation of the larger tracheal trunks. In so far as the mechanics of respiration is concerned, the insect could be compared in several respects with the bird or mammal. The active expansion of the abdomen of the insect is analogous to the increase in size of the body cavity in the bird or of the thoracic cavity in the mammal. During the expansion of the abdomen the hemocoele of the insect becomes larger and the intracoelomic pressure must decrease and become less than atmospheric. The outside air, having free access to the tracheal system through the spiracles, will then cause the thin-walled and elastic air sacs, *wherever they are located,* to dilate and fill. During expiration the abdomen is compressed and made smaller, the intracoelomic pressure becomes greater than atmospheric, and this increased pressure, transmitted by the blood to all parts of the body, will cause the air sacs to collapse and empty. The greater the total capacity of the air sacs the greater must be the possible ventilation at each respiration, within the limits of expansion of the abdomen.

The walls of the ordinary tracheae contain a spiral chitinous thickening, and offer a considerable resistance to pressure tending to collapse or distend them. The cavities of the insect's body have no connection with the lumina of the tracheae. Hence, in an insect possessing no air sacs or such distensible structures, both the inspiration and expiration of air would be impossible. The ventilation of the tracheal trunks could be accomplished only by the mechanism of diffusion.

The number of air sacs in an insect may be surprisingly great. Landois[3] stated that there are about 550 in the male of *Melolontha vulgaris.* Packard[4] counted fifty-three sacs in the head alone of *Melanoplus femur-rubrum.* According to Newport[1] there are air sacs even in the mandibles of the stag beetle. In some of the very active insects the sacs form a veritable complex in the thorax and abdomen. It is noteworthy that many of the sacs arise from the smaller tracheal branches at a considerable distance from any spiracle. Even the largest ones usually do not open immediately from the spiracular trunks, but from the transverse or longitudinal trunks. Neither are the air sacs blind pockets at the ends of tracheal tubes, but

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[1] *Trans. Linn. Soc.,* 20: 419, 1851.

[2] Comstock, "An Introduction to Entomology," Ithaca, N. Y., 1925.

[3] *Zeitschr. f. wiss. Zool.,* 17: 105, 1867.

[4] First Report U. S. Entomol. Comm., p. 269, Washington, 1878.

usually have many efferent branches to adjacent tissues which are short as compared with the total length of the tracheal tree.

If the above view of the function of the air sacs is correct there would be an enormous advantage in having such a great number of small sacs scattered throughout the body, rather than a few large ones. Each sac would serve to ventilate the section of tracheal tube between it and the nearest open spiracle. The agitation given to the column of air in the tortuous tracheae would be very effective in aiding the diffusion of gases. Krogh[5] and Winterstein[6] have expressed doubts as to the possibility of diffusion alone through the long, narrow tracheal tubes being able to supply an adequate amount of oxygen to the tissues, especially during activity. Krogh has further shown experimentally in a series of ingenious experiments that diffusion alone is sufficient for an adequate gas exchange in the great majority of larvae, all pupae, and in the smaller and more lethargic adult insects. In the larger and more active forms with well-developed powers of flight, however, diffusion alone must be inadequate. If the function of the air sacs outlined above is correct, the difficulty disappears. For the comparatively short distances between the air sacs and the tissues the process of diffusion would supply a sufficient amount of oxygen, even to the organs of the head which are farthest removed from any spiracles. The parallel development of the air-sac system with the powers of flight would indicate the efficiency of the mechanism for supplying an adequate gas exchange for such an oxygen-consuming activity.

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COMPOSITION OF BONE, VII. EQUILIBRATION OF SERUM SOLUTIONS WITH $CaHPO_4$

IT is generally taken for granted that bone consists chiefly of $Ca_3(PO_4)_2$ and that when calcium phosphate is deposited in the bones it is in the form of this compound, tricalcium phosphate. There have been several notable attempts to account for the deposition of tricalcium phosphate on the basis of solubility product considerations. Holt, La Mer and Chown[1] interpreted their experiments as showing that "serum is normally supersaturated with tertiary calcium phosphate to the extent of more than 200 per cent." Not only normal serum is supersaturated but also "Even in active rickets this ion product is greater than that required to precipitate $Ca_3(PO_4)_2$," according to Holt.[2] Sendroy and Hastings[3] obtained similar experimental data with $Ca_3(PO_4)_2$, but concluded that supersaturation can not be the sole explanation "for the apparently abnormal amounts of calcium in serum," and that the data indicate "that calcium exists in serum in abnormal amounts bound to some substance or substances which hold it in solution in unionized form."

In a previous communication[4] we presented evidence which indicated that serum does not contain abnormal amounts of calcium and that serum and inorganic serum solutions are not supersaturated but are undersaturated. Furthermore, the important substance appears to be $CaHPO_4$ and not $Ca_3(PO_4)_2$. Our calculations showed that in inorganic serum solutions with Ca × P products less than 30, $[Ca^{++}] \times [HPO_4'']$ is less than the solubility product of $CaHPO_4$, and that in solutions with Ca × P products ranging from 40 to 60, $[Ca^{++}] \times [HPO_4'']$ is very nearly equal to the solubility product of $CaHPO_4$.

This value for $K'_{s.p.}CaHPO_4$, the solubility product of $CaHPO_4$, was obtained by extrapolation from data in the literature. The present paper is a preliminary communication giving the value of $K'_{s.p.}CaHPO_4$ obtained experimentally at the ionic strength of serum.

An inorganic serum solution was made up containing 8 mg per cent. calcium and 3 mg per cent. phosphorus. Aliquots of this solution were equilibrated at room temperature with an excess of crystalline $CaHPO_4$. It was found that equilibrium was obtained after shaking for only one hour, and that the equilibrium was independent of the amount of the solid phase. The concentrations both of calcium and of phosphorus were *greater* at equilibrium than in the initial solution. Fifteen experiments were performed at room temperature; the mean value obtained for $K'_{s.p.}CaHPO_4$ was 3.2×10^{-6}. Twenty similar experiments were performed at 38°; the mean value obtained for $K'_{s.p.}CaHPO_4$ at 38° was 3.4×10^{-6}.

In making these inorganic serum solutions, the initial Ca × P product was varied from zero to 60; some contained high calcium and low phosphorus concentrations; others contained the reverse. After equilibration, the ion product obtained in all these solutions was identical. Equilibration with $CaHPO_4$ caused an *increase* in the concentration of calcium or

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[5] *Pfl. Arch. f. d. ges. Physiol.*, 179: 113, 1920.

[6] "Hdb. d. vergl. Physiol.," 1, p. 111, Jena, 1921.

[1] L. Emmett Holt, Jr., Victor K. La Mer and H. Bruce Chown, *Jour. Biol. Chem.*, 64: 509, 567, 1925.

[2] L. Emmett Holt, Jr., *Jour. Biol. Chem.*, 64: 579, 1925.

[3] Julius Sendroy, Jr., and A. Baird Hastings, *Jour. Biol. Chem.*, 71: 783, 797, 1927.

[4] M. J. Shear and Benjamin Kramer, *Jour. Biol. Chem.*, 79: 125, 1928.